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Re: Single Beam and MultiBeam Point Based Comparison and Validation of Conditional Simulation Approach.
Lower Passaic River Restoration Project
W912DQ-08-D-0017, Task Order 0010

Single Beam and Multibeam bathymetry data sets collected in 2007 and 2008 were used to assess the following:

- Point differences in elevation recorded during single beam and multibeam surveys conducted from August 23 to 26, 2007, and September 9 to 22, 2007, respectively. This analysis provided an assessment of the uncertainty in the measurement of elevation, assuming that no events occurred in the period between the two surveys. Violation of this assumption would result in overstatement of actual measurement errors. Therefore, these are upper bounds on the measurement errors.

- Validation assessment of bathymetric interpolation by conditional simulation. This was done by:
    - Creating a 1990's- type single beam survey by sampling the 2007 mutibeam data along the 1995 bathymetry survey transect locations. This was referred to as "2007 at 1995 transect locations".
    - Performing conditional simulation of the 2007 at 1995 transect locations, on a 6 by 9 grid.
    - Comparing the conditional simulation results with the true 2007 multibeam data at the unsampled simulated grid points.

- Cursory comparison of the 2007 and 2008 multi beam survey data sets relative to reported elevation changes estimated from single beam surveys.

The results of each of these analyses are summarized below.

Point Differences in 2007 Single and Multibeam Survey Data Sets

The single beam survey in 2007 contained both transverse tracks (across flow) at 100 feet spacing and three longitudinal tracks. Three point based comparisons were made using both the single beam data and the multibeam data. First, the elevations recorded in the transverse and longitudinal single beam tracks were compared to each other at the locations where they intersected. Second and third, the single beam transverse tracks and longitudinal tracks were compared to the multibeam data by determining which single beam depth value was closest to each point of the 3 ft by 3 ft subsampled multibeam data with a maximum allowed distance between the two depths of 1.5 ft. The results of these comparisons are as follows:

- A histogram of depth comparisons at the crossings of along-river and across-river single-beam tracks is given in Figure 1a. The average elevation difference is 0.03 feet (standard deviation = 0.29 feet). About 57 percent of the differences are within +/- 0.15 feet.

- A histogram of the comparison of the 2007 single beam transverse tracks to the multibeam data is given in Figure 1b. The average elevation difference is 0.1 ft, standard deviation of 0.35ft and the mean absolute error is 0.25 ft.

- A histogram of the comparison of the 2007 single beam longitudinal tracks to the multibeam data is given in Figure 1c. The average elevation difference is 0.03 ft, standard deviation is 0.44 ft, and the mean absolute error is 0.29 ft.

- A map showing the point differences between the longitudinal and transverse tracks single beam compared to the multi beam elevation is shown in Figure 2. In this map, the elevation differences are shown in three categories: 1) less than -7 inches (below the 5th percentile), 2) between -7 and 6 inches (5th to 95th percentile) and 3) greater than 6 inches (above the 95th percentile). In general, there is no systematic spatial pattern in the distribution of the differences outside the 5th and 95th percentiles, where differences would typically be expected.

- Observed variances between surveys combine the variances associated with the individual single beam and multibeam surveys. The exact partitioning of the variances among the two surveying methods is unknown. However, the standard deviation of 0.44 ft represents the combined variance of the two surveys and is an upper bound estimate of the variance associated with either survey alone. If it is assumed that each survey was equally precise, one may conclude that the standard deviation for an individual survey is given by √(0.5*Standard Deviation^2). This results in standard deviations of 0.2 ft for the point to point comparison of cross flow *vs.* longitudinal transects, 0.25 ft for the cross flow single beam *vs.* multibeam comparison, and 0.31 ft for the longitudinal single beam *vs.* multibeam comparison.

- These observed errors are somewhat smaller than those typically estimated using error propagation techniques. This is likely the result of the conservatism in some steps of the error propagation methods.

Validation of Conditional Simulation Methodology

The validation of the conditional simulation method to spatial interpolation of single beam bathymetry data was conducted to evaluate the performance of the method in determining the elevation and associated probability especially off the single beam transect tracks. The conditional simulation approach detailed in the CSM was applied to the 2007 on 1995 transect locations to simulate elevations at grid locations where actual elevation measurements exist from the multibeam survey. A histogram of the differences between the average simulated surface and the actual surface is given in Figure 3a. The mean absolute difference is 0.27 ft, and the 5^{th} and 95^{th} percentile of the differences are between – 6 and 6 inches, respectively, a result that is comparable to that obtained in the single beam versus multibeam point comparison. Figure 3b compares the histogram of the validation difference for the conditional simulation from Figure 3a to the difference from the point based single beam and multibeam comparison from Figure 1b. The distributions of the differences are comparable, and show more than 65 percent of the difference are within 3 inches or less.

The degree of agreement in the validation analysis was further tested to determine the probability threshold for a 5 percent false positive rate for various elevation differences. A false positive error or Type I error is defined in this context as simulating a substantial erosion change beyond a depth difference cutoff when in truth such a difference shouldn't occur. Figure 4 presents a summary of the results, highlighting in yellow the probability thresholds for a 5 percent false positive rate. For a 6-inch erosion cutoff, a 5 percent false positive rate occurs when the probability threshold is set at ~50 percent. Therefore, when evaluating the results of the bathymetric change analysis performed using conditional simulation, a significant bathymetric change of 6 inches should be assessed at the 50 percent probability threshold. Note that the probability threshold for a 5 percent false positive rate increases as the depth criteria decreases. Figure 5 shows the spatial locations where the false positive results occurred for a 6-inch difference cutoff with at least 50 percent probability. The false positive locations are preferentially located close to bridges where uncertainties in bathymetry data are expected to be higher due to steep surfaces and positioning signal interference due to the bridge superstructure. Errors are also observed at the edges of the simulation where data coverage and interpolation are less robust.

Cursory Comparison of 2007 and 2008 Multibeam Surveys

Roger Flood of Stony Brook University performed a cursory comparison of the 2007 and 2008 multibeam surveys in five segments (A to E) along the Passaic River (Figure 6) in order to determine if there were patterns in bathymetric change that could be discerned based on these high-resolution data sets. This new data set can help to understand the nature and origin of bathymetric changes estimated from the single beam surveys. The results of the comparison are as follows:

- For segment A around RM 13.6, sun illuminated bathymetry images[1] show sand waves with some mounds in 2007 (Figure 7a) but a smoother bed with no sand waves but with many more mounds visible in 2008 (Figure 7b). Bathymetric comparison along the longitudinal transect in segment A (drawn in blue in Figures 7a and 7b) show the 2008 surface to be deeper with no sand waves relative to 2007 (Figure 7c). This segment was eroded between the 2007 and 2008 survey period; Figure 7d shows the extent of erosion, including the erosion of the sand waves.

- For river segment B around RM 9.75, sun illuminated bathymetry images in 2007 (Figure 8a) and 2008 (Figure 8b) show a coarse bed beneath the bridge in the center of the segment. However, the coarse bed in the 2008 bathymetric surface in this area is about 0.2 ft deeper (Figure 8c) than in 2007. Figure 8d shows the extent of the scour and deposition around the bridge area based on the difference between 2008 and 2007 survey results. This uncertainty around bridges observed between the multibeam surveys is consistent with that reported above in the conditional simulation validation analysis. River segment C around RM 8.85 (Figure 9a though d) further illustrate the effect of bridges and other structures on bathymetry uncertainty. Figure 9d also shows a sand wave field (shown in red) south of the bridge that developed between 2007 and 2008.These results also suggest a difference of 0.1 to 0.2 feet in the area around the bridge structure. Assuming that the absolute elevation of these areas did not change between surveys, these observations suggest a survey-to-survey absolute error of 0.2 ft or less. As will be seen in subsequent survey comparisons, this absolute error is small in comparison to many of the observed elevation changes.

- For river segment D around RM 4.05, the 2007 sun illuminated images show large bed scours in 2007 (Figure 10a), but these areas are filled in 2008 (Figure 10b), an illustration of the sediment dynamics in the river. A transverse transect in this segment shows both erosion of more than 6 inches and deposition of more than a 1 ft moving from the Northwest bank to the Southeast bank of the river (Figure 10c). Significant erosion and deposition changes can be observed throughout this segment as shown in Figure 10d.

[1] Sun illuminated bathymetry images are false color images created by bathymetric analysis. These images were created at the State University of New York (SUNY), Stony Brook.

- For river segment E around RM 1.6, the sun illuminated images in 2007 show a smooth surface with some local depressions (Figure 11a). In 2008, the images shown an irregular surface with some local depressions (Figure 11b). A transect along the flow direction shows small deposition at one end and large erosion change of more than 2 ft at the other (Figure 11c). Note that this elevation change is more than an order-of-magnitude greater than the offset between surveys suggested above. Overall this area is erosional with some patches of significant deposition along the edges. Part of the erosion observed can be attributed to ship activities.

This cursory analysis identifies areas of significant bathymetric change between the two multibeam surveys, despite their relative closeness in time (ca. 1 year). In many areas, particularly at RM 4.05 and 1.6 (Areas D and E), the scale of change was six inches or more. Additionally, the results show geomorphic changes that correspond with the elevation changes.

The geomorphic changes apparent in the multibeam survey can be considered characteristic of the processes that cause the elevation changes noted in the historical bathymetric surveys. That is, the same processes that cause these features to come and go also cause the changes in absolute elevation. However, the spacing of the bathymetric survey cross sections (100 feet apart) and the scales of the geomorphic features (<<100 feet) are very different. Thus it is not the appearance of these features that is causing the observations of bathymetric change. Additionally, changes of statistical significance generally require multiple bathymetric nodes to correlate; thus the scale of the detected bathymetric changes between surveys generally spans more than several hundred feet.

With that said, the occurrence of wave features and the appearance and disappearance of large sediment mounds can be considered representative of an active layer of sediment that is mobile and is subject to routine movements. This layer represents the active volume of sediments into which solids delivered from the head-of-tide, solids delivered from Newark Bay, and solids eroded from deeper layers are mixed. It is this layer that is still highly contaminated with dioxins (~300 parts per trillion).